HP-PS design progress: Super-ferric magnet option

Yannis PAPAPHILIPPOU

`LAGUNA-LBNO HP-PS design Meeting
24/09/2012

HP-PS parameters

Parameters	PS2	HP-PSa	HP-PSb	HP-PSc	HP-PSd	HP-PSe
Circumference [m]	1346.4	1256	1009	763	**1256**	
Symmetry	2-fold	**3 / 4-fold**				
Beam Power [MW]	0.37	**2.0**				
Repetition rate [Hz]	0.42	2	2	2.6	**1.3**	**1.0**
Kinetic Energy @ inj./ext. [GeV]	4/50	4/50	4/40	4/30	**4/50**	
Protons/pulse [10^{14}]	1.1	1.25	1.6	1.6	**1.9**	**2.5**
Dipole ramp rate [T/s]	1.4	6.1	6.0	7.5	**4.0**	**3.1**
Bending field @ inj/ext. [T]	0.17/1.7	0.17/1.7	0.21/1.7	0.27/1.7	**0.17/1.7**	
Fractional beam loss [10^{-4}]	35.1	6.5	5.0	4.0	**6.5**	
Space-charge tune-shift H/V	-0.13/-0.2	**-0.2/-0.2**				
Lattice type	NMC arc, doublet LSS and DS	**Resonant NMC arc, doublet LSS**				
Norm. emit. H/V [μm]	9/6	6.8/6.7	8.6/8.5	11/11	**10.5/10.3**	**13.7/13.4**
Max. beta H/V [m]	**60/60**					
Max. dispersion [m]	3.2	**5**				
Dipole Gap height [mm]	80	85	95	108	**105**	**120**
Rms electrical Power [MW]	5.2	23.8	21.2	22.7	**19.3**	**17.0**

- Getting 2MW power not straight-forward (even with a fully dedicated linac)
  - Ramp rate, space-charge, losses, acceptance, space (cost)
- The less constrained ring is the more costly one, i.e. high-energy, longest ring, with lowest repetition rate and with the closest parameters to PS2
- Last parameter iteration to be done considering super-ferric magnets with around 2.T peak field
  - Reduction in circumference, electrical consumption, normalized emittance, aperture, and thereby cost

Super-ferric HP-PS

- Circumference determined by energy and bending field @ extraction, and the filling factor (i.e. total bending length over circumference)

$$C \approx 3.335 \frac{2\pi\beta E}{B F_f}$$

- Filling factor for SPS and PS is ~2/3 (FODO cells) but for PS2 is ~0.5 (NMC cells – mandatory for low-losses in a high-power machine) and difficult to be increased
- Considering a 2.1T bending field (super-ferric dipole) @ 50GeV kin. Energy the circumference can be reduced to around 1km (1017m)
- The repetition rate can remain to 1s with ramp rate of 3.1T/s

Parameters	PS2	HP-PSe	SF HP-PS
Circumference [m]	1346.4	1256	1017
Bending field @ ext. [T]	1.7		2.1
Total Energy @ ext [GeV]	51	51	51
Filling factor	0.47	0.5	

SF HP-PS Intensity

Parameters	PS2	HP-PSe	SF HP-PS
Circumference [m]	1346.4	1256	1017
Protons/pulse [10^{14}]	1.1	2.5	2.5
Harmonic number	180	167	135
Number of bunches	168	161	129
Protons/bunch [10^{11}]	6.5	15.6	19.5
Rel. β/γ @ inj.	0.98/5.26		
Norm. emit. H/V [μm]	9/6	13.7/13.4	12.2/11.9
SC tune-shift H/V	-0.13/-0.2	-0.2/-0.2	

$$\Delta Q_{x,y} = -\frac{r_0 N_p C}{2(2\pi)^{3/2}\sigma_z \beta\gamma^2 \epsilon_{x,y}}$$

- Limited by space-charge, and other collective effects, especially at injection
- Beam considered as for PS2 with a 25ns bunch structure, although this is not necessary
- Machine filled with bunches leaving a 150ns gap for kicker rise/fall time (300ns for PS2)
- Assumed that bunch length is scaled with square root of harmonic number
- For keeping space-charge tune-shift below -0.2, vertical emittance increased accordingly, and transverse acceptance reduced

Electrical power

Parameters	PS2	HP-PSe	SF HP-PS
Dipole ramp rate [T/s]	1.4	3.1	3.1
Total dipole length [m]	632.8	628	508.5
Gap height [mm]	80	120	113
Rms Power [MW]	5.2	17.0	-

- Repetition rate imposed by source/linac
- For linear ramp and very short flat bottoms the ramp rate much higher than the one of PS2
- Super-ferric option reduces drastically electrical power but extra cost/power for cryogenics

Losses control

Parameters	PS2	HP-Pse	SF HP-PS
Circumference [m]	1346.4	1256	1017
Beam Power [MW]	0.37	2.0	
Total uncontrolled loss limit [kW]	1.3	1.3	1.0
Fractional beam loss [10^{-4}]	35.1	6.5	5.0

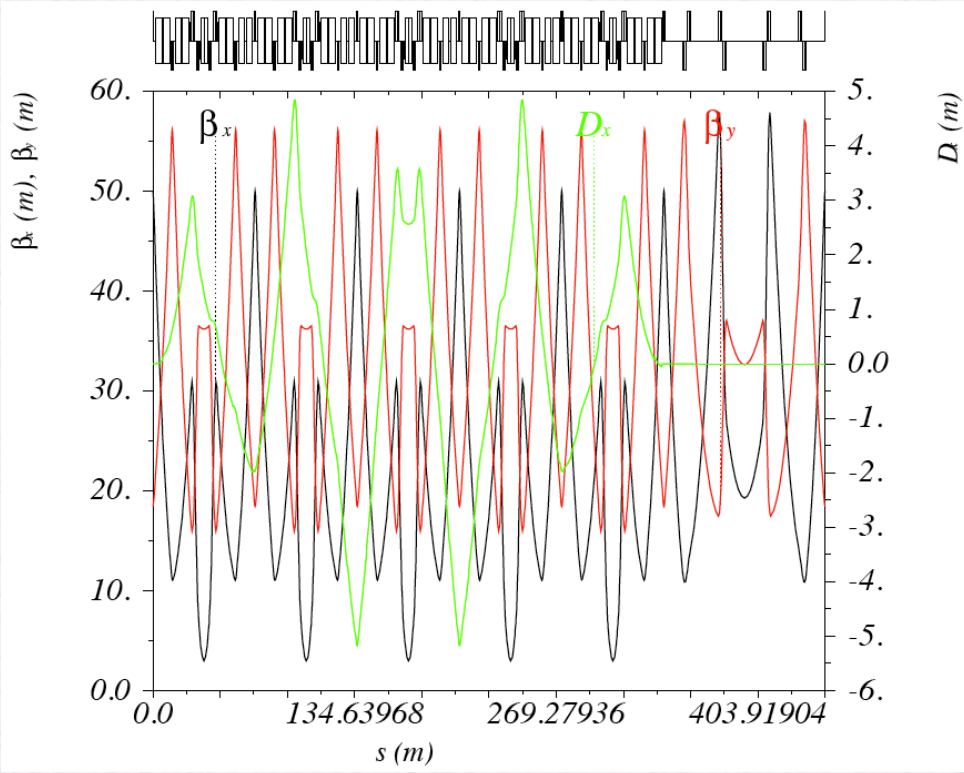
- Limit of uncontrolled losses around the ring of 1W/m
- Assuming all losses occur at extraction (pessimistic), the fractional beam loss limit is set to a few 10^{-4}, i.e. almost an order of magnitude lower than PS2
- Consistent with requirements of other high-power synchrotrons (e.g. SNS accumulator ring)
- More difficult for shorter ring
- Design (and space) of an efficient collimation system is mandatory

Layout and lattice

- Design based and adapted from PS2
- 3 or 4-fold symmetric ring to accommodate in separate LSS injection/collimation, extraction and RF
- NMC lattice necessary to avoid transition and reduce losses
- Use resonant NMC cells to increase filling factor (no DS)
- Doublet LSS leave more space for BT equipment, collimation and RF
- Need to fit the ring in the present CERN layout and according to the first phases of LAGUNA (position of SPL to HP-PS transfer-line, HP-PS to target, injection to SPS…).

Example: Resonant NMC

- Starting from PS2 resonant arc
- 5 NMC arc cells with horizontal phase advance tuned to 8π
- Due to space constraints can only achieve 46GeV for dipole field of 1.7T
  - Not an issue for slightly shorter long straight sections and higher field magnets
- Limited tunability (provided only by LSS in the horizontal plane)
- Very good non-linear dynamics performance



HP-PS parameters

Parameters	PS2	HP-PSe	SF HP-PS
Circumference [m]	1346.4	1256	1017
Symmetry	2-fold	3 / 4-fold	
Beam Power [MW]	0.37	2.0	
Repetition rate [Hz]	0.42	1.3	
Kinetic Energy @ inj./ext. [GeV]	4/50		
Protons/pulse [10^{14}]	1.1	1.9	2.5
Dipole ramp rate [T/s]	1.4	3.1	
Bending field @ inj/ext. [T]	0.17/1.7	0.17/1.7	0.21/2.1
Fractional beam loss [10^{-4}]	35.1	6.5	5.0
Space-charge tune-shift H/V	-0.13/-0.2	-0.2/-0.2	
Lattice type	NMC arc, doublet LSS and DS	Resonant NMC arc, doublet LSS	
Norm. emit. H/V [μm]	9/6	13.7/13.4	12.2/11.9
Max. beta H/V [m]	60/60		
Max. dispersion [m]	3.2	5	
Dipole Gap height [mm]	80	120	113
Rms electrical Power [MW]	5.2	17.0	-

Next steps for 2012

- Finalize parameters for super-ferric magnet option
- Produce a first order optics design and layout
  - Arc, LSSs for injection/extraction, collimation and RF
  - Tunes, chromaticity, correction
  - SF magnet parameters
  - Start discussion on RF system parameters
  - Adapt PS2 collimation

- Design progress followed in monthly (or bi-weekly) meetings

- The "players":
  - J. Alabau-Gonzalvo, A. Alekou, F. Antoniou, YP (ABP)
  - B. Goddard, A. Parfenova (BT)
  - I. Efthymiopoulos, C. Lazaridis (MEF)
  - M. Benedikt, R. Steerenberg, Fellow (OP)
  - F. Gerigk, E. Chapochnikova (RF)